GREEN TECHNOLOGY

TECHNOLOGY STATUS REPORT

Electric Vehicles:

Technology Development for a Cleaner Environment

Ministry of the Environment

ISBN 0-7778-7467-9

TECHNOLOGY STATUS REPORT

Electric Vehicles:

Technology Development for a Cleaner Environment

September 1997

Prepared by:
Andrew Tomingas
Environmental Technologies Services
Industry Conservation Branch
Ministry of the Environment

Cette publication technique n'est disponible qu'en anglais.

PIBS 3645E

Printed on recycled paper

250 - 05 - 98

Disclaimer

This report was prepared for the Ontario Ministry of the Environment as part of the Ministry's information transfer activities. We hope that the report will provide perspective and encourage discussion in a rapidly changing technological world. The views and ideas expressed in this report are based on interpretations of various referenced authors and do not necessarily reflect the position or policies of the Ministry of the Environment, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Acknowledgement

The author would like to thank Tom Lewinson (Executive Director, Electric Vehicle Association of Canada) and Sian Lie (Vice President, Elettra Technology Inc.), for their assistance in providing technical reviews of this report. This report would not have been possible without their essential contributions.

Table of Contents

List of Tables

List of Appendices

List of Acronyms and Abbreviations

A	Ampere
AC	Alternating Current
BDCPMM	Brushless DC Permanent Magnet Motor
DC	Direct Current
EV	Electric Vehicle
ICE	Internal Combustion Engine
k.p.h.	kilometres per hour
kW	kilowatt
kWh	kilowatt-hour
Li-ion	Lithium-ion
NaS	Sodium Sulphur
NiFe	Nickel-iron
NiMH	Nickel-metal hydride
NO_x	Nitrous oxide
OEM	Original Equipment Manufacturer
Pb-acid	Lead-acid
SCIM	Squirrel-Cage Induction Motor
SRM	Switched-Reluctance Motor
W	Watt
Wh	Watt-hour
ZEV	Zero Emission Vehicle

Executive Summary

Internal combustion engines in vehicles emit airborne hydrocarbons, ozone, carbon monoxide and other compounds which pollute the air. Cars and trucks also are significant sources of carbon dioxide which may contribute to global warming.

Electric vehicles which use systems such as batteries and fuel cells to power them do not directly emit pollutants or carbon dioxide and they promise significant environmental benefits. A number of technical and economic impediments must be addressed however before the marketplace accepts EVs. These barriers include lack of suitable infrastructure, an inability to quickly charge large numbers of batteries, a limited number of models and higher cost.

The lack of suitable battery-manufacturing facilities also is a primary impediment to the mass production of EVs. Current battery-manufacturing plants are only pilot scale (e.g. $30 million capital cost per plant), with each plant annually making less than 5,000 batteries. However, mass-production plants (e.g. $500 million capital cost per plant) should be operating by 2001 or 2002.

Much recent attention has focussed on California and its ZEV legislation. The original legislation required OEMs to sell electric vehicles in the state by 1998. However, automobile manufacturers and the oil industry argued that consumers would not buy early versions of EVs due to their high cost, limited range and short battery life.

The California Air Resources Board (CARB) amended the legislation in March 1996 removing the requirement that two per cent of model year 1998 vehicles, or approximately 22,000 cars, must be EVs. The CARB instead agreed with the seven large-volume OEMs that they each would produce 3750 advanced-technology demonstration EVs by 2003.

This revision raised questions for the states of New York and Massachusetts which had adopted the original California ZEV legislation. Massachusetts has since adopted the revised law. However New York state continues to mandate that 2 per cent of new vehicles sold in 1998 in the state must be EVs. Financial penalties will be incurred by the OEMs if this level is not met.

The lone market opportunity in Canada for electric vehicles currently is the Vancouver area because of its moderate climate and the support for EVs by the provincial government. However, EVs will have to be accepted widely in cold climate areas throughout North America. An estimated population of 300 million is needed to sustain a viable EV automobile industry, yet seventy per cent of the population in North America lives in cold climate areas.

The introduction of EVs in Ontario would bring significant environmental benefit. Annual emissions from the transportation sector in the province currently total 630,000 tonnes of NO_x, 390,000 tonnes of hydrocarbons (HC), 3.6 million tonnes of carbon monoxide (CO), and 48 million tonnes of carbon dioxide (CO_2). Replacing an ICE vehicle with an EV reduces emissions of NO_x by 88.1 per cent, HC by 93.9 per cent, CO by 99.6 per cent and CO_2 by 75.8 percent (Heath *et al.*, 1994). If EVs comprised one per cent of the of the highway transportation vehicle fleet in Ontario, annual emissions would be reduced by 5,500 tonnes of NO_x, 3,700 tonnes of HC, 35,900 tonnes of CO, and 363,800 tonnes of CO_2.

Canada could also benefit economically from the wide introduction of EVs. Opportunities to develop and manufacture motors, motor controllers, batteries/fuel cells, charging systems, and advanced technologies such as flywheels would be created. The manufacture of "gliders" for the California market would also be an opportunity for domestic branch plants of the Big Three automobile manufacturers.

1. Introduction

Internal combustion engines in vehicles emit airborne hydrocarbons, ozone, carbon monoxide and other compounds which pollute the air in major cities. Cars and trucks also are significant sources of carbon dioxide which may contribute to global warming.

Catalytic converters on vehicles cut emissions of many pollutants by more than 90 per cent, but they are not the only solution to the problem. Catalytic converters also do not reduce emissions of carbon dioxide.

Electric vehicles which use systems such as batteries and fuel cells to power them do not directly emit pollutants or carbon dioxide and they promise significant environmental benefits. A number of technical and economic impediments must be addressed however before EVs are accepted in the marketplace. This report focuses on battery-powered EVs for the light-duty vehicle market.

2. Background

The electric car made its debut in Berlin in 1882 and it dominated the streets of Europe and America until 1910. Electric propulsion seemed as likely a fuel for transportation as gasoline in the early years of the automobile. Each method had its advantages, but neither emerged as a clear choice of consumers.

The invention in 1912 of the electric starter to replace the hand crank for gasoline-fuelled automobiles, combined with Henry Ford's ability to mass produce the gasoline-powered automobile, secured the future of the ICE. Enthusiasm for EVs waned although interest in them remained with enthusiasts and automobile OEMs.

The development of EV technology has accelerated since the late 1980s, but not because of normal market forces. The market for EVs has been created by legislation, particularly that enacted in California in 1991 in response to severe air pollution problems in the state and notably in the Los Angeles Basin.

Air pollution is not as severe in Canada as it is in California, but automobiles and the burning of fossil fuels cause much of the pollution which threatens the quality of the urban environment. Vehicles also are a significant source of greenhouse gases. Canada has a large supply of relatively "clean" electricity from its variety of hydro, nuclear and fossil-fuelled generating stations which means that EVs could reduce emissions of greenhouse gases per vehicle mile by 60 per cent and ozone-related emissions completely (Webb, 1993).

3. The State of the Technology

Electric vehicles have prompted the further technical evolution of components which have been originally designed and refined for the ICE automobile. These areas include: vehicle aerodynamics, high-strength/light-weight composite materials, high efficiency motors, energy storage systems which deliver both good performance and driving range, regenerative braking, low rolling resistance tires, and advanced electronics such as motor controllers and ultra capacitors.

A number of technological and market barriers still must be overcome before EVs are commercially viable. One major area in which progress is needed is in storage batteries and fuel cells. These systems must have:

- high energy density (for long range).
- high power density (for good performance).
- fast recharging/refuelling time.
- long cycle life.
- competitive first cost.

Issues which must be addressed to promote public acceptance of dedicated battery-powered EVs include:

- it must be a second family car.
- what percentage of the population can afford to buy a special-purpose car?
- would tax incentives encourage consumers to buy EVs?
- consumers are unlikely to spend much more on EVs just to benefit the environment.
- the infrastructure needs to support the wide use of EVs.

The scope of the study here is limited to the overall vehicle and the motor and energy storage systems (e.g. traction batteries and flywheels).

3.1 The Vehicle - Purpose-built or Conversion

An EV is a vehicle with an electric propulsion system. The basic requirements are a power source such as a battery, flywheel or fuel cell, a motor controller and an electric traction motor.

Electric vehicles may be conversions of existing ICE models or be purpose-built. Both types are being developed worldwide by large and small automobile OEMs (Table 1). Vehicles such as the General Motors S-10 pickup, Ford Ranger, Chrysler EPIC, Solectria Force and Toyota RAV4-EV are EV conversions. They consist of a "glider" (i.e. a car frame without an engine) fitted with EV components. The BMW E1 and E2, Honda EV Plus, GM EV1 and Solectria Sunrise are designed and developed as EVs.

Bombardier Inc. is one Canadian OEM of EVs. The company makes a two seat Neighbourhood Electric Vehicle (NEV) in Sherbrooke, Quebec. The NEV is designed for short-distance residential travel and it is targeted at the nearly 90 per cent of drivers in North America who travel less than 15 km per day in their car. The National Institute of Standards and Technology, which is the US equivalent of Transport Canada, will shortly be establishing regulations for NEVs.

All these EVs except those from BMW are commercially available. Automobile OEMs however will need to diversify the range of available EV models if they are to comply with legislation in California and elsewhere that requires by 2003 that 10 per cent of sales of new vehicles must be EVs. As an illustration, the highly popular ICE powered Ford Taurus currently constitutes only 2 per cent of new vehicle sales in North America.

Table 1 Worldwide EV Development Programs

Vehicle	Developer	Type	Status	Battery	Motor	Range Federal Urban Driving Schedule (km)	Top Spd. (kph)	Est. Cost (Cdn)
E1/E2	BMW/Unique Mobility	4-passenger car	Concept.	NaNiCl 200 kg	BDCPMM 32 kW	240	120	N/A
Neighbourhood Electric Vehicle	Bombardier	2-passenger sub-compact car	Commercially-available	Sealed Pb-acid	SRM	50	40	$10 k
EPIC	Chrysler Corp.	Passenger/ Cargo minivan	Prototype	Pb-acid	SCIM 46 kW	180	105	$135 k
Ranger EV	Ford Motor Co.	Pickup truck	Commercially-available	Sealed Pb-acid	SCIM	80	120	$43 k
EV1 (5th Generation Impact)	General Motors	2-passenger sub-compact sports car	Commercially-available	Pb-acid 500 kg or NiMH	SCIM 102 kW	105 Pb-acid 220 NiMH	125	$47 k
Impact	General Motors	2-passenger sub-compact sports car.	Prototype	Pb-acid 500 kg	SCIM 102 kW	190	120	$95 k
Chevy S-10	General Motors	Pickup truck	Commercially-available	Pb-acid 635 kg	SCIM 85 kW	100	120	$45 k
EV Plus	Honda Motor Co.	4-passenger high-hat wagon	Commercially-available	NiMH	BDCPMM	205	130	$72 k
Nissan Prairie Joy	Nissan Motor Co.	4-passenger electric van.	Available in 199	Li-ion	BDCPMM 62 kW	> 200	120	N/A
106	Peugeot	Compact passenger car	Commercially-available	NiCd 260 kg	SCIM	120	90	$25 k
Sunrise	Solectria Corporation	4-passenger sub-compact sports car	To be commercialized.	Pb-acid or NiMH	2 SCIM 21 kW	175	120	$20 k
Force (Geo Metro)	Solectria Corporation	4-passenger compact car	Commercially-available	Pb-acid or NiMH	2 SCIM 21 kW	160	113	$60 k
RAV4-EV	Toyota Motor Corporation	4-passenger sports utility vehicle	Commercially-available	NiMH	BDCPMM 45 kW	195	130	N/A

3.2 EV Motors

A motor for an EV must be compact and light. The motor can be mounted in the transaxle which connects the two driven wheels to keep transmission losses between the motor and the wheels as low as possible. The Ford Ranger uses this system. An alternative is to build the motors directly into the wheels of the vehicle as in the GM EV1 (WMCCL, 1994).

Variable torque and speed control are essential for EV propulsion systems. Direct current drives have been used widely for EV propulsion systems due to their simple controllability. Recent advances in semi-conductor technology, power electronic components, and high speed microprocessors have increased the popularity of AC drives over DC drives.

The three types of electric motors which currently are most suitable for EV propulsion systems are the:

- squirrel-cage AC induction motor (SCIM).
- switched-reluctance motor (SRM).
- brushless DC permanent-magnet motor (BDCPMM).

3.2.1 Squirrel-Cage AC Induction Motors

The design of SCIMs for variable frequency drive application is quite different from the conventional fix frequency motor design. Squirrel-Cage AC Induction Motors typically are used for constant speed work. Electric vehicles require constant horsepower over a wide speed range. Most current EV development programs such as those in Table 1 utilize SCIMs (WMCCL, 1994).

3.2.2 Switched-Reluctance Motors

Switched-Reluctance Motors have a very simple and rugged rotor and they produce more output than a SCIM of the same size. The rotor for a SRM has no windings which means lower rotor losses, it is easier to cool and it can be run at a very high speed. Westinghouse Motor Company is currently investigating the use of SRMs for EVs although their design for this application is still in the development stage (WMCCL, 1994).

3.2.3 Brushless DC Permanent-Magnet Motors

Brushless DC Permanent-Magnet Motors are capable of higher specific output which means that they are more compact and lighter compared to SCIMs and SRMs. Motor weight can be reduced by 30 per cent by using permanent magnets instead of wound field poles. Motor efficiencies are high because power losses which result from field windings are eliminated. Brushless DC Permanent-Magnet Motors run at up to 6,000 to 7,000 rpm and their part-load efficiency may be even better than AC induction motors. Unique Mobility is one company which is at the forefront of BDCPMM development.

Obstacles associated with the BDCPM motor which need to be overcome include:

- permanent magnets (PMs) can be accidentally de-magnetized.
- the high cost of PMs.
- the durability of PMs.

3.3 The Battery

Energy storage systems which are not performance and cost competitive with hydrocarbon fuels are the biggest obstacle to the commercialization of EVs.

The California Air Resources Board battery audit identified the lack of suitable facilities to make batteries as the primary impediment to the mass production of EVs. Current plants are only pilot scale (e.g. \$30 million capital cost per plant) with each plant annually making less than 5,000 batteries. However, mass-production battery plants (e.g. \$500 million capital cost per plant) should be operating by 2001 or 2002. The battery-pack currently represents 50 per cent of the cost of an EV and the cost of batteries will remain high until they can be mass-produced.

The high cost of some types of batteries is further compounded by their limited cycle life. A Pb-acid battery-pack lasts for less than 100,000 km and it must be replaced every few years. Limited cycle life is of much less concern with NiMH and Li-ion batteries which can last more than 300,000 km.

Vehicles which use hydrocarbon fuels have better performance and longer range than vehicles that use electrochemical batteries. This is due to the superior energy density, measured as the specific energy, of hydrocarbon fuels. Gasoline has an energy density of about 12,000 Wh/kg. The specific energy of a typical Pb-acid battery is only 30 - 50 Wh/kg while that of a Li-polymer battery exceeds 200 Wh/kg.

Gasoline also is superior to batteries in terms of its specific power. Specific power is a measure of potential acceleration and maximum speed of the vehicle.

Current advances in battery technology will address at least some of these performance and cost disadvantages. Mitsubishi reports that they are developing a manufacturing process which will enable them to produce a Li-ion battery which costs 40 per cent less than the Sony-Nissan Li-ion battery. Hydro Quebec and 3M are at the pilot plant stage of developing a Li-polymer battery which will allow a vehicle to travel more than 400 km between charging. General Motors plans to offer NiMH batteries as well as the current Pb-acid batteries in an attempt to double the range of its EV1 model to about 220 km (Law, 1997).

The performance characteristics for several existing and proposed batteries for EVs are summarized in Table 2.

Table 2 Short-Term, Mid-Term and Long-Term EV Battery Technologies

Battery	Manufacturer	Specific Energy (Wh/kg)	Specific Power (W/kg)	Cycle Life
Pb-acid	Electrosource	41.5	65	900
Li-ion	Sony-Nissan	120	150	~ 1,000
Li-polymer	Hydro Quebec- 3M	> 200	N/A	> 1,000
Nickel-metal hydride	Amotsoshita-Toyota	80	160	> 1,000
Nickel-metal hydride	GM-Ovonics Battery Co.	81	158	> 1,000

A disadvantage of any type of battery is that it takes more time to recharge than it does to fill up an ICE vehicle with gasoline. Even quick-charging the battery of an EV may take 15 minutes.

Climate is another factor which affects the performance of batteries in EVs. Electric vehicles cannot be operated year-round in most parts of Canada because their batteries lose significant energy capacity during winter. This problem can be overcome by an on-board thermal battery management system which maintains an acceptable operating temperature for the battery during cold weather (Heath *et al.*, 1994). Thermal battery management systems generally involve reversible heat pumps and diesel-fired heaters.

Vehicular parasitic losses in cold climate conditions also may reduce the range of current dedicated electric vehicles by 60 - 80 per cent to less than 40 km if there is more than 15 cm of snow. These parasitic losses can be limited to 15 - 20 per cent if the battery pack is properly insulated.

Electromechanical batteries (EMBs), commonly known as flywheels, also might be used to address some deficiencies of existing battery systems. Electromechanical batteries are high-speed power devices which are ideally suited to load levelling a drive system. The specific energy of EMBs is estimated to be between 500 - 600 Wh/kg, but their major benefit is a power density of between 5,000 - 10,000 W/kg. This would be significantly better than currently available battery technologies.

The high power density of the EMB combined with the high energy density of the chemical battery in a hybrid drive system could thus address both the performance and range requirements of the EV. Electromechanical batteries however have yet to be demonstrated in an EV application (Riezenman, 1992).

4. The Stakeholders and Key Client Groups

Legislation and not normal market forces has created the recent interest and increases demand for ZEVs. The most significant statute is that enacted by the California Air Resources Board (CARB) in 1991 in response to severe air pollution problems in the state and notably in the Los Angeles Basin. While this law forces automakers to produce EVs, it does not compel customers to buy them.

Automakers and the oil industry particularly argued that the law that OEMs must sell EVs in California by 1998 would be counterproductive. They reasoned that consumers would not buy early versions of the EVs because of their high cost, limited range, and short battery life, and that the ultimate market acceptance of EV technology would be compromised.

In March 1996, CARB revised the legislation. The Board removed the requirement for the model year 1998 that two per cent of new vehicles sold must be EVs. Instead the CARB agreed with the seven large-volume OEMs that the OEMs would each produce 3,750 advanced-technology demonstration EVs by 2003. General Motors, Chrysler, Ford, Toyota, Nissan, Honda and Mitsubishi, each of whom sell annually more than 35,000 vehicles in the state, were covered by the agreement (Heath *et al.*, 1994).

Table 3 highlights the proposed implementation schedule for ZEVs in California.

Table 3 California Clean Air Standards for Zero-Emission Vehicles

Air Quality Requirements (Emissions, g/mile)			Percentage of Vehicles Sold Meeting Emissions Standards					
HC	NO_x	CO	1998	1999	2000	2001	2002	2003
0.00	0.0	0.0	0	0	0	0	0	10

This revision to the California ZEV law raised questions for the states of New York and Massachusetts which had adopted the original legislation. Massachusetts has since adopted the revised law. New York state however continues to mandate that two per cent of new vehicles sold in 1998 must be EVs. Financial penalties will be incurred by the OEMs if this level is not met.

Texas and twelve other states, mostly in the northeast and mid-Atlantic regions, also have adopted all or part of the CARB rules. These states buy approximately 40 per cent of the cars sold in the United States (Bedard, 1992). Other states may soon follow.

General Motors, Ford and Chrysler while opposed to the CARB ZEV legislation all have responded by developing prototype or concept EVs. General Motors is aiming for the retail market with their EVs, while Ford and Chrysler are targeting fleet customers. Many smaller OEMs also are working to commercialize battery-powered EVs.

General Motors first produced EVs in 1916 when GMC Truck built a number of electric trucks which used Pb-acid batteries. In the 1990s, GM introduced the two-seat Impact. The Impact is a purpose-built EV which uses Pb-acid batteries and AC induction motors. The model which is now known as the EV1 can accelerate comparably to an ICE-powered car. It can go from zero to 100 k.p.h. in about 8 seconds and it has a top speed of over 160 k.p.h., although a speed governor keeps it under 125 k.p.h.. The range of the vehicle at 90 k.p.h. is approximately 105 km, but is estimated at 220 km with a NiMH battery.

General Motors now has invested more than $1 billion in the EV1 which is built at the company's assembly plant in Lansing, Michigan. General Motors also is developing EVs in Europe. Additional information is contained in Appendix A.

The EV1 is the first vehicle to carry a General Motors designation rather than of one of the company's marketing divisions. The EV1 can be leased through twenty-six Saturn retailers in Los Angeles, San Diego, Phoenix and Tucson. When it was first available in December 1996, the company adopted stringent criteria for lessees accepting only ten per cent of applicants.

General Motors had leased only 176 EV1s by late April 1997, well below the rate at which they could be made. GM subsequently reduced the monthly lease rate by 25 per cent from $715 to $540, and now aims to lease 100 EV1s per month. It will also provide refunds to existing operators of the EV1 (Law, 1997).

The reduced cost of leasing and plans to install NiMH batteries instead of Pb-acid batteries in the EV1 comes as GM faces competition from Honda's EV Plus and the RAV4-EV from Toyota.

General Motors also leases to commercial fleets an electric version of the Chevrolet S-10 which uses the same technology as the EV1. Further technical and performance specifications of the S-10 are outlined in Table 1. The company also recently formed a business unit called Delco Propulsion Systems which will market EV parts and propulsion systems, including those that were incorporated into the EV1, to makers worldwide of cars, buses and trucks.

The Ford Motor Company offered its EV named the Ecostar on a 30 month lease demonstration program. The Ecostar was based on the company's European Escort van and it operated on NaS batteries coupled with an AC induction motor. The Ecostar had a top speed of approximately 120 k.p.h. and a range of about 160 km in mixed urban-highway driving. However the Ecostar vehicle fleet was scrapped at the end of the demonstration program. The company now offers the Ranger pickup truck which is built as an EV. More details on its technical and performance specifications are in Table 1. The Ford EV development program also is based in Michigan.

The Chrysler EPIC is based on the Plymouth Voyager minivan. The EPIC uses Pb-acid batteries and a Westinghouse AC-induction motor. The EPIC has a top speed of approximately 105 k.p.h. and a practical range of about 180 km. Gliders for the model will be manufactured at the company's minivan plant in Windsor and these will be converted to electric propulsion in the US.

The Japanese OEMs are more secretive about their ZEV programs. They have demonstrated various concept cars, but their models for the California market have been cloaked in secrecy. It is speculated that the vehicles will use storage systems based on hydrogen, such as fuel cells, or ICEs which are fuelled by hydrogen.

Honda and Toyota do have EVs which are already available commercially. Honda's EV-Plus is designed and built as an EV while Toyota's model is based on the RAV4 sports utility vehicle. Nissan will be introducing an electric van in 1998.

Many entirely new companies also are emerging as potential manufacturers of EVs or their components. The Big-Three automakers are likely to buy parts from secondary manufacturers or they could sell entire EVs from other manufacturers under their own name.

Peugeot is already selling EVs in Europe and it is the OEM which is probably most advanced in developing on-road EVs for commercial sale. Peugeot has no current plans to sell EVs in the United States although other OEMs may seek to "re-badge" Peugeot EVs for the California market.

US Electricar once offered converted GEO-Prizms and Chevrolet S-10 pickups as EVs for about $54,000. The company now converts commercial vehicles such as postal delivery trucks to operate as EVs. Solectria Corporation of Wilmington, Massachusetts, founded in 1986, plans to manufacture about 20,000 Sunrise EVs in 1998. The target price for this purpose-built, all-composite EV will be under $30,000. The price includes the Pb-acid battery (South Coast Air Quality Management District, 1995). Solectria is also converting GEO Metro and Chevrolet S-10 pickup trucks for operation as EVs. Appendix C contains additional information. The EVs which are converted by Solectria are supplied to the Canadian marketplace by Sirdo Canada Inc. of St. Thomas, Ontario.

A number of other worldwide EV development programs are highlighted in Table 1.

Many automakers are individually pursuing their own programs to research and develop batteries. The Big Three US automakers along with the US Department of Energy and the Electric Power Research Institute formed the United States Advanced Battery Consortium (USABC) in 1991 to develop advanced batteries for EVs and to improve their performance and range. The consortium has an overall budget of $350 million and its objective is to work with advanced battery developers and research companies to produce battery designs which can compete with ICE vehicles. The goal is to develop several advanced, long-term storage battery technologies (Heath *et al.*, 1994).

Electric vehicles built before 2000 primarily will use battery technologies such as Pb-acid and NiMH. These battery technologies meet the USABC mid-term goals for various key parameters except for cost.

A group of lead producers and four battery companies formed the Advanced Lead-Acid Battery Consortium (ALABC) in March 1992 to research and develop advanced Pb-acid batteries for EV applications (Heath *et al.*, 1994).

The advanced battery development goals for the USABC and the ALABC are outlined in Table 4.

Table 4 United States Advanced Battery Consortium / Advanced Lead-Acid Battery Consortium Technology Development Goals

State of Technology	Battery Type	Specific Energy (Wh/kg)	Specific Power (W/kg)	Cycle Life
Near-term	Lead-acid	56 (50)*	79 (150)*	450 (500)*
Mid-term	Nickel Metal Hydride	80	150	600
Long-term	Li-polymer or Li-ion	> 200	> 400	1,000

NOTE: * Technology development goals of the Advanced Lead-Acid Battery Consortium are in parenthesis.
Specific energy is a measure of the range of an EV.
Specific power is a measure of the performance (ie. acceleration, top speed) of an EV.

American Flywheel Systems of Seattle, Washington, and Flywheel Energy Systems Inc. of Kanata, Ontario, are leaders in flywheel research and development. The latter company is currently developing a 1 kWh high performance flywheel with a rotational speed of between 45,000 and 50,000 rpm.

Norvik Technologies Inc. of Mississauga, Ontario, has been developing a fast battery charger for Pb-acid, NiFe, NiCd and NiMH batteries. The new 150 kW charger can charge a battery from complete discharge to 95 per cent of capacity in about 10 minutes. Norvik has partnered with Chrysler Corporation for the development. Both the Chrysler EPIC and the Ford Ranger have been engineered with the Norvik charger's electronic controller as an integral part of the EV.

Ontario Hydro is one utility which is interested in EV technology. The Chairman of Ontario Hydro in 1993 stated "Electric vehicles represent a very logical industrial prospect for the Province of Ontario, which is already a major automobile manufacturer. It also makes a lot of sense for a company such as Ontario Hydro to be interested in the subject . . . Widespread use of electric vehicles would be a welcome development in terms of urban air pollution. It would also lead to a more efficient use of Ontario Hydro's resources, because the batteries used for these vehicles would be recharged for the most part during off-peak generating periods."

Ontario Hydro's current position is to monitor the development of EV technology although it is not a present priority for them. The utility is waiting for a strong customer demand before they become more proactive.

5. The Impact on the Environment

Vehicles are major emitters of VOCs and NO_x. Oxides of nitrogen and certain VOCs react in the presence of sunlight to form ozone which contributes to smog. Fifty per cent of VOCs and 64 per cent of NO_x from unnatural sources are emitted by vehicles.

Both ozone and its precursors can be transported over long distances. In fact poor air quality in the Windsor-to-Cornwall corridor is primarily due to the transport of ozone and its precursors from the US. Emissions in the US must therefore be reduced before the levels of ozone in Ontario will be lowered.

An exception to this is urban areas where local vehicles may be the most significant sources of NO_x. Reduced emissions from the transportation sector would directly improve air quality. The transportation sector also is responsible for seventy six per cent of the emissions of carbon monoxide, although this pollutant is not transported over long distances.

A key to reducing emissions of greenhouse gases also is to shift away from carbon-intensive energy sources. This is particularly true in the transportation sector. The supply in Canada of relatively "clean" electricity from the variety of hydro, nuclear and fossil-fuelled generating stations means that EVs could reduce emissions of greenhouse gases per vehicle mile travelled by 60 per cent and ozone-related emissions completely (Webb, 1993).

While EVs are considered to be ZEVs and do not produce emissions at the point of use, electricity must be generated to charge their batteries. This means that EVs are not completely pollution-free. Emissions from a central power plant source however, are easier to control than from thousands of individual sources (Webb, 1993).

The introduction of EVs in Ontario would bring significant environmental benefit. Annual emissions from the transportation sector in the province currently total 630,000 tonnes of NO_x, 390,000 tonnes of hydrocarbons (HC), 3.6 million tonnes of CO, and 48 million tonnes of carbon dioxide (CO_2). Replacing an ICE vehicle with an EV reduces emissions of NO_x by 88.1 per cent, hydrocarbons by 93.9 per cent, carbon monoxide by 99.6 per cent and CO_2 by 75.8 percent (Heath *et al.*, 1994). If EVs comprised one percent of the of the highway transportation vehicle fleet in Ontario, annual emissions would be reduced by 5,500 tonnes of NO_x, 3,700 tonnes of HC, 35,900 tonnes of CO and 363,800 tonnes of CO_2.

6. The Economics of EVs

The OEMs have made a concerted effort to develop and produce a viable EV, but the current price of EVs is uncompetitive with that of ICE-vehicles. The cost to establish the infrastructure to support the wide use of EVs also is a major factor. The South Coast Air Quality Management District in 1995 estimated that the United States would need to invest $15 billion in infrastructure to service EVs if they were used widely. As some time will elapse before EVs gain a significant share of the market, the benefits of economics of scale would not be realized for some years.

Electric vehicles would however be cheaper to operate on a daily basis. A Light-duty Vehicle powered by gasoline which is driven for 50,000 km per year consumes 230 gigajoules (GJ) of energy. The same vehicle powered by electricity annually consumes only 65 GJ. This 165 GJ of energy saved is equivalent to 4,560 litres of gasoline worth $2,370 (at a gasoline cost of 52 cents per litre). Ontario annually would save one petajoule of energy if only one per cent of the current provincial on-highway transportation fleet was EVs.

7. The EV Infrastructure

7.1 Connections

An EV must connect to the AC power grid for charging. To fully charge a passenger car with a typical battery capacity of about 25 kWh in 8 hours requires a connection which can handle more than 3 kW. Fortunately a standard 220 V / 30 A line easily meets this need.

The transfer of energy from the power grid to the EV can be by ohmic contact or magnetic induction. Both systems are very safe. Inductive charger coupling eliminates exposed conductors. Ohmic contact utilizes a 7-pin connector and there is a delay of 10 seconds before any current is passed to the battery. The flow of energy is cut off within 3-millionths of a second of disconnection.

Which charging system will prevail is yet to be determined. General Motors utilizes an inductive technology to charge the battery of the GM EV1 and the Chevrolet S-10 electric pickup truck. Nissan also has adopted the inductive technology. Toyota has purchased patents for both inductive and ohmic contact technologies. If the public believes that ordinary plugs are dangerous and inductive chargers are safe, psychology and not technology ultimately may decide the issue (Riezenman,1992).

7.2 Quick-Charging

Studies of driving patterns suggest that the vast majority of cars daily travel no more than 40 km. Most electric vehicles can therefore be easily charged overnight at their home base. In densely populated cities such as Toronto, some EVs may not have a home base and must be charged at public charging stations or use curbside chargers.

One study in California estimated that 85 per cent of privately owned or commercial fleet EVs will be charged overnight at home. An additional 10 per cent of vehicles will be charged through opportunity charging. Typical sites for opportunity charging would be near major highways. They would allow vehicles to be trickle-charged in four hours.

Only five per cent of cars will be charged in minutes by quick charging. Most experts however agree that it will be difficult to sell EVs which cannot be charged in minutes. Although they may not use the feature very often, people will want to know that they can quick charge their EVs if needed.

To fully charge an EV battery from near depletion in 15 minutes requires in the order of one hundred kilowatts of power. This capacity is not available in typical homes. Special industrial quick charge stations will be needed (Riezenman, 1992). These stations will buy cheap energy during off-peak periods (e.g. at 3¢ per kWh), store it in an underground battery storage system (e.g. using Zinc Bromine battery system) and then resell it to day-time customers at a much higher cost (e.g. 30c per kWh).

7.3 Charging Scenarios Within The Existing Utility Infrastructure

Four possible scenarios are envisaged for charging EVs; home charging, workplace charging, opportunity charging in the transportation corridor, and oil companies becoming energy distribution companies.

The diversity of load will allow 25 kWh and 35 kWh batteries typically found in EVs to be opportunity trickle-charged over 4 hours or convenience trickle-charged over 8 hours in electrically-heated homes. The existing utility infrastructure in residential areas however will not accommodate quick-charging unless the system hardware including transformers and secondary cables is upgraded or fewer homes are served by each transformer.

A more detailed assessment of the different charging scenarios is contained in Appendix D.

The capacity of the recharger also is limited. To recharge a typical 25 kWh passenger car battery completely in 5 minutes from a 220 V line requires more than 1000 A.

These numbers do not mean that electric vehicles are impractical or impossible. They do mean that the role of EVs will be limited until batteries are substantially improved. Electric vehicles should thus initially be promoted as local-delivery vans and as second cars to be used for short trips like commuting or shopping.

Since most automobile mileage consists of such trips in any case, EVs might be more accurately regarded as primary vehicles. An ICE-vehicle would be reserved as a second car for special purposes such as occasional long trips.

As EVs become more common, utilities will upgrade the infrastructure in existing subdivisions and they will design facilities in new subdivisions to accommodate the increased load.

7.4 Utility Impact

The main role of utilities will be to supply electrical energy to charge EVs. The present electricity system can meet the additional demand for energy if most EVs are charged overnight. More generating capacity may be needed if a significant number of EVs are charged during the day when demand is already higher.

7.5 Demand-Side Management

Electric vehicles are attractive to utilities because they are a potential user of electricity during off-peak hours when there is excess generating capacity.

Utilities are examining a variety of demand side management measures to promote charging during these hours and to discourage it during peak periods. The most likely is a special rate structure for operators of EVs. Time-of-day, interruptible, and real-time pricing are three possible options.

Time-of-day pricing already is available. It encourages night-time charging by offering a substantially reduced rate to users during off-peak hours.

An interruptible tariff qualifies customers for reduced rates by allowing the utility to interrupt charging during periods when demand for electricity by other users is greatest.

Real-time pricing changes the rate charged on an hourly basis to reflect the actual cost of providing the electricity. The rates for the next day would be calculated daily and electronically communicated to customers. This would allow customers to save money by charging their vehicles when the rate is lowest (Riezenman, 1992).

7.6 Distribution

Where EVs are charged will determine if their introduction will strain distribution facilities. Initial buyers of EVs likely will be relatively affluent people who live in communities that already have more than adequate service. No distribution problems are anticipated if EVs are trickle-charged.

Fleet vehicles pose less of a question since they are generally not purchased on impulse. The longer lead time gives the utility ample opportunity to determine what if any action to take (Canadian Electrical Association, 1991).

The quick-charge option presently is not viable regardless of who buys EVs (Section 7.3 and Appendix C)

8. Hybrid Electric Vehicles

The inadequate range of EVs and the limited infrastructure to charge them will curb immediate demand by the public for EVs. Electric propulsion may be encouraged by the development of hybrid vehicles in which a battery driven electric motor is augmented by a engine which runs on gasoline or an alternate fuel. The auxiliary engine could be operated when the battery is depleted or when driving conditions necessitate the use of an ICE.

Toyota Motor Corporation has developed such an advanced hybrid system to power its Tercel model. The model is called the Prius and its hybrid system incorporates a high-efficiency 1.5 L gasoline engine and an EV power system which is based on NiMH batteries. Toyota estimates that the hybrid vehicle will emit only half the amount of carbon dioxide and emissions of hydrocarbons, carbon monoxide, and NO_x will be cut by about 90 per cent compared to a normal ICE vehicle (EVAA Press Release, 1997). The hybrid vehicle is commercially-available in Japan and Toyota plans to begin marketing this vehicle in North America by the end of 1998. Toyota is currently pushing for an equivalent-to-ZEV ruling for the Prius hybrid. The hybrid vehicle does however currently cost $4,000 more than its ICE counterpart.

Honda and Nissan plan to offer similar hybrid vehicles starting in 1998.

Volvo has developed a hybrid vehicle which it has dubbed the Environmental Concept Car (ECC). The ECC is a mid-size, four-door sedan based on the Volvo 850 model. The ECC has a diesel-powered gas turbine engine that turns a high-speed electric generator. The generator provides voltage directly to an electric motor at highway speeds. Excess power is used to charge the on-board NiCd battery pack. The ECC weighs 1580 kg. It has a top speed of 175 k.p.h. and will accelerate from zero to 96 k.p.h. in 13 seconds. The ECC when powered only by batteries has a range of between 90 to 150 km depending on the driving conditions. The gas turbine generator increases the range to 670 km (Kenzie, March 1992).

The Ontario Ministry of the Environment has assisted several companies including Ontario Bus Industries and Alupower Canada to design and develop proof-of-concept hybrid vehicles and ZEVs.

9. EV Opportunities for Canada

California is driving the development of the EV industry in North America. Air pollution is not as severe in Ontario, but automobiles and the burning of fossil fuels cause much of the pollution which threatens the quality of the urban environment.

Existing EV technology however greatly limits the appeal of EVs in most parts of Canada. Vehicular parasitic losses particularly when there is significant snowfall reduces the driving range of current EV vehicles by up to 80 per cent to an unacceptable 40 km or less. Batteries also lose significant energy capacity during the winter months. The lone market opportunity in Canada for electric vehicles currently is the Vancouver area because of its moderate climate and the support for EVs by the provincial government.

The automobile industries in Canada and the US however are fully integrated. Canadian manufacturers play a major role in the production of cars even though consumers in Canada buy only 8 per cent of new vehicles sold in North America.

To design vehicles to meet unique Canadian emission requirements would be inefficient and would raise the cost of the vehicle. Adopting the US cleaner air standards demonstrates a commitment to addressing air quality and will result in environmental gains. This argues for the continued harmonization of Canadian vehicle emission standards with those in the US (Canadian Council of Ministers of the Environment Report, 1995). The timetable to establish acceptance of ZEVs in Ontario and other parts of Canada can however be adjusted while ZEVs are developed which are more technically and economically viable.

Meanwhile there is an opportunity for domestic industry to develop and manufacture technology or to develop component parts for ZEVs for California even though the Big Three automakers will assemble most of the EVs in the United States. This includes opportunities to develop and manufacture motors, motor controllers, batteries/fuel cells, charging systems, and advanced technologies such as flywheels. The manufacture of "gliders" would also be an opportunity for domestic branch plants of the Big Three automobile manufacturers.

One local company which is already successful in the ZEV market is Norvik Technologies Inc. of Mississauga, Ontario. Norvik has been developing a fast battery charger which can be used with any battery type. The goal is to reduce the time it takes to charge a battery from complete discharge to 95 per cent of capacity from 25 minutes to about 10 minutes. Norvik has partnered with Chrysler Corporation for the development. The Chrysler EPIC and the Ford Ranger have been engineered with the Norvik charger's electronic controller as an integral part of the EV.

Oshawa Prototype Services which is a spin-off division of General Motors of Canada Ltd. has developed an epoxy die process which is ideal for limited number production runs. The GM plant in Lansing, Michigan, uses the epoxy die process to manufacture parts for the EV1. Alcan Aluminium Ltd. provides the aluminum for the EV1 program.

Other companies within Ontario which are poised to take advantage of the wider commercialization of EVs include SRE Controls Inc. of Waterloo who manufacture controllers, and Elettra Technology Inc. of Hamilton. Elettra is developing a broad range of high end electric motors including a SCIM for use in EVs. The company was founded by the former EV motor development group at Westinghouse Motor Company of Canada Ltd.

Sirdo Canada Inc. of St. Thomas, Ontario sells EV cars and pickup trucks which are manufactured by Solectria Corporation.

10. Summary and Recommendations

Opportunities for EVs in the near term will be restricted to niche markets such as California and the other southern and western US states. Elsewhere EVs face many technical and economic impediments which must be addressed before they are accepted in the global marketplace. These barriers include lack of suitable infrastructure and its inability to accommodate different battery charging scenarios, and limited model availability and higher capital cost of EVs.

The lack of suitable battery-manufacturing facilities is particularly identified as a primary impediment to the mass production of EVs. Current battery-manufacturing plants are only pilot scale (e.g. $30 million capital cost per plant), with each plant annually making less than 5,000 batteries. However, mass-production plants (e.g. $500 million capital cost per plant) should be operating by 2001 or 2002.

Automobile OEMs will need to diversify the range of available EV models to broaden their appeal to consumers. Otherwise it will be difficult to meet the requirement that 10 per cent of sales of new vehicles in California by 2003 must be EVs. As an illustration, the highly popular ICE powered Ford Taurus currently constitutes only 2 per cent of new vehicle sales in North America.

One viable option to increase acceptance of electric propulsion is to further develop the hybrid vehicle. Such vehicles could be powered by a combination of fossil fuel and electricity or they could utilize an all-electric system by coupling a flywheel with a battery.

The lone current market opportunity in Canada for electric vehicles is the Vancouver area because of its moderate climate and the support for EVs by the provincial government. In many other parts of North America the viability of EVs is limited by currently available battery designs and climate considerations.

Even so legislation in some cold climate states demands that significant quantities of EVs are sold within five years. Massachusetts mirrors California in its requirement that 10 per cent of sales of new vehicles in the state by 2003 must be EVs. New York state mandates that 2 per cent of new vehicles sold in 1998 must be EVs.

Electric vehicles will have to be accepted widely in cold climate areas throughout North America. An estimated population of 300 million is needed to sustain a viable EV automobile industry, yet seventy per cent of the population in North America lives in cold climate areas.

Canada should move to harmonize its standards for air quality with those of the US, but it should not mandate the use of technologies such as EVs which are not yet ready for full commercialization and which are not widely accepted by the consumer. Canada can however benefit from the wide introduction of EVs. Opportunities to develop and manufacture motors, motor controllers, batteries/fuel cells, charging systems, flywheels and "gliders" for EVs represent significant possibilities for domestic industry. The 1998 World Electric Vehicle Conference in Orlando, Florida, and the 2000 conference in Montreal, Quebec, should be significant occasions for Canadian manufacturers to demonstrate their expertise in EV technologies.

11. References

Bedard, P., Car and Driver, What's the Deal on Electric Cars?, May 1992

Canadian Council of Ministers of the Environment, The Task Force on Cleaner Vehicles and Fuels, October 1995

Canadian Electrical Association, The Prospects for Electric Vehicles in Canada, and the Impact on the Utilities, November 1991

EVAA (Electric Vehicle Association of the Americas) Press Release, March 1997

Heath, M., Renne, G., and Carr, C., Electric Vehicles - Economic Costs, Environmental Benefits, June 1994

Kenzie, J., The Toronto Star, Hybrid Vehicles, March 1992

Law, A., The Toronto Star, GM Electric Vehicle Sales Flag, May 1997

Riezenman, M., IEEE Spectrum, Electric Vehicles, November 1992

South Coast Air Quality Management District, Building Markets for Low-Emission Technologies and Clean Fuels - A Status Report on Commercialization and Technology Transfer, January 1995

Webb, R. F. Corporation Ltd., The Environmental Effects of Transportation Fuels, September 1993

WMCCL, Improved Electric Motor Performance for EV Propulsion Systems, March 1994

APPENDIX A General Motors EV1

GM

Electric Vehicles

The Program

✧ *In spring 1993 General Motors completed production of 12 engineering development vehicles, based on the 1990 Impact showcar. These vehicles are being tested to ensure that this highly advanced, ultra-efficient vehicle meets customer requirements as well as safety standards.*

✧ *When testing is complete, General Motors will produce up to 50 vehicles for evaluation by hundreds of potential electric vehicle customers.*

✧ *The experience and information gained from this program will help General Motors prepare to mass-produce electric vehicles for the late-90s and will help develop the market and infrastructure electric vehicles will require.*

The Vehicle

✧ *The car includes all of the features customers have come to expect from their vehicles, such as: ABS, cruise control, compact disc player, plus many other driving comforts.*

✧ *The vehicle is an energy efficient 2-passenger, 2-door coupe like the original Impact showcar and is designed to comply with all of the vehicle standards which would make it "street legal" and safe.*

✧ *A computer-controlled AC Induction motor, combined with powerful lead-acid batteries, provides instantaneous throttle response, smooth, shift-free acceleration and a silent idle.*

✧ *A solar reflective windshield and an electric heat pump ensure ultra-efficient passenger compartment climate control.*

✧ *The ultra-lightweight aluminum structure provides optimum strength and energy efficiency.*

✧ *Our market research has determined that 68 percent of drivers studied drove less than 50 miles per day, a total daily mileage well within the range of our electric vehicle.*

IMPACT 3 SPECIFICATIONS

PERFORMANCE

Range at 80% Depth of Discharge	EPA City	≈ 70 miles
	Highway	≈ 90 miles
0-60 mph Acceleration		8.5 seconds
Top Speed (Electronically Regulated)		75 mph
Charge Time from 80% Depth of Discharge (Using 220 Volt, 6.6 kW charging equipment)		2 to 3 hours

DIMENSIONS

Length	169.8 inches
Width	69.3 inches
Height	50.5 inches
Wheelbase	98.9 inches
Drag Coefficient	0.19
Curb Weight	2910 pounds

SPECIAL FEATURES

✧ 137 Horsepower Three-Phase AC Induction Motor
✧ 16.8 kWh Maintenance-Free Lead-Acid Battery Pack - 312 Volts
✧ Electric Motor-Driven Heat Pump Climate System
✧ Inductively Coupled Charging System
✧ IGBT Power Inverter Module - 102 kW
✧ Electro-Hydraulic Power Steering
✧ Electro-Hydraulic Braking System
✧ Rigid, Welded and Bonded Aluminum Alloy Body Structure
✧ Blended Regenerative Braking
✧ Low Inflation Tire Monitor
✧ High-Voltage Isolation Assurance

STANDARD FEATURES

✧ Dual Air Bags
✧ Anti-Lock Power Brakes
✧ Traction Control
✧ Low Rolling Resistance Tires
✧ Aluminum Wheels
✧ Scotchgard Seats
✧ Double Wishbone Front Suspension
✧ AM-FM/Cassette/CD
✧ Electriclear Windshield
✧ Solar Glass
✧ Dual Power Outside Mirrors
✧ Cruise Control
✧ Power Door Locks
✧ Power Windows

Do you have questions or comments? Please call us at (800) 25-ELECTRIC (800-253-5328), or write:

GM Electric Vehicles
432 N. Saginaw St.
Flint, MI 48502-9922

Printed on recycled paper.

APPENDIX B Ford Ranger

1998 FORD RANGER

1998 FORD Electric RANGER

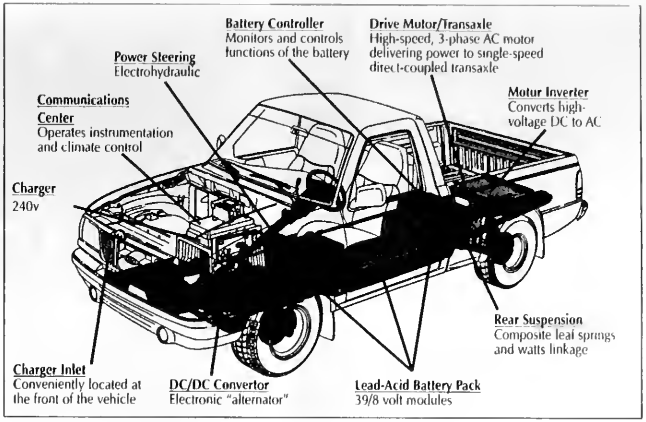
Overview of the Ranger Electric

The 1998 Ford Ranger EV pickup truck is based on the best-selling compact truck, the Ford Ranger and incorporates the same "Best-in-Class" design features as its gasoline counterpart. The Ranger EV is powered by proven lead acid batteries and is equipped with third-generation, electric vehicle-specific, powertrain components and electronics.

The Ranger EV is Ford's 1998 production electric vehicle and has been designed and tested to be reliable, durable and "Built Ford Tough." The Ranger EV is warranted by Ford and provides a "Best-in-Class" electric-powered pickup truck. Select Ford dealerships will provide sales, service, and complete customer satisfaction for the advanced technology Ranger EV.

The Ford Ranger EV has been built with fleet customer needs in mind, including such features as:
- Cargo carrying capacity
- Usable payload
- 4-wheel ABS
- Climate control
- Dual air bags

Additionally, the Ranger EV includes components unique to EV's such as:
- Regenerative braking
- Electrohydraulic power steering
- On-board charger
- Optional battery heater
- Re-programmable electronics
- Conductive charging



Vehicle

Model year	1998
Bodystyle	Styleside, regular cab pickup
Wheelbase	Short wheelbase
Payload (base vehicle)	700 lbs.
Gross vehicle weight (est.)	5400 lbs.
Dimensions	Same as 1998 gasoline-powered Ranger

Powertrain (located between rear wheels)

Motor	90 hp, high efficiency, liquid cooled, 3-phase AC induction
Transaxle (integrated with motor)	Single-speed, rear-wheel drive using half-shafts

Standard Features

Dual Air Bags	Occupant safety protection
Electronic Microprocessor Control Units	Ford designed, state-of-the-art
-Battery Controller	Monitors functions of battery
-Motor Inverter	Converts high-voltage DC to 3-phase AC
-Communications Center	Operates instrumentation and climate control
Heater	Electric resistance
Regenerative Braking	Energy recovery to increase range
Economy Drive	Driver controlled with increased regenerative braking
DC/DC Convertor	Electronic "alternator"
4-wheel ABS	Straighter stopping control under most conditions
Power Steering	Electrohydraulic
Wheels and Tires	Lightweight aluminum wheels, low rolling resistance tires

Battery

Type	Sealed lead acid
Modules	39/8-volt
Voltage	312 volt system
Battery energy capacity rating @ FUDS	23 kwh (19 kwh at 85% discharge)
Charger	On-board, 240v/30 amp utilizing safe, convenient conductive technology

Performance Targets

0-50 mph acceleration	12.5 seconds (gasoline Ranger <12 sec.)
Top speed (governed)	75 mph
Range	
- FUDS cycle @ 72F without A/C or heater operation	58 miles
- Customer range @ 72F	50 miles
- Customer range @ 32F including heater	35 miles

Warranty

Vehicle	Same as 1998 gasoline powered Ranger
Batteries	2-year; second year prorated

Options

Air Conditioning	Energy efficient unique EV design
Battery Heater	On tether for cold climates
Spare Tire and Jack	Tire mounted in pickup bed

For more information:
phone 800-ALT-FUEL • fax (810) 333-9710

Printed on recycled paper.

#I-34265

APPENDIX C Solectria-Manufactured Electric Vehicles

SOLECTRIA

THE LEADER IN ELECTRIC VEHICLE TECHNOLOGY

With over one million miles of on-road experience, Solectria presents the Force electric sedan ...

Offering state-of-the-art electric vehicle technology in a safe, comfortable, and spacious four-door sedan, the Solectria *Force* is the *only* production electric sedan that met *all* of the grueling requirements established by the nationwide electric utility industry and U.S. Department of Energy coordinated EV America program. Solectria EVs today deliver reliable performance in challenging weather and geographic conditions ranging from Arizona to Vermont.

The *Force* features smooth, whisper-quiet, shift-free operation, regenerative braking, a full-size trunk, and a convenient onboard charger requiring only a standard household outlet. A Tri-Power Selector facilitates efficient driving and maximizes battery life, while an optional battery thermal management system maintains range in cold weather and an optional Cabin Preheat system warms your vehicle before you climb in.

Low-maintenance, user-friendly, and cost-effective Solectria electric vehicles make a positive environmental statement without sacrificing personal comfort. Solectria ... *the leader in electric vehicle technology.*

SOLECTRIA

SOLECTRIA CORPORATION
68 Industrial Way · Wilmington, MA 01887 USA
508-658-2231 / Fax 508-658-3224 / www.solectria.com

VEHICLE SPECIFICATIONS

System Power		42 kW
Length		164"
Width		70"
Height		56"
Curb Weight		2460 lb
Top Speed		70 mph
Efficiency @ 45 mph		137 Whr/mi
Acceleration:	0 - 30 mph	8 sec
	0 - 50 mph	18 sec
Range:	Standard Lead Acid	50 mi @ 45 mph
	Optional Ovonic Nickel-Metal Hydride	105 mi @ 45 mph

STANDARD

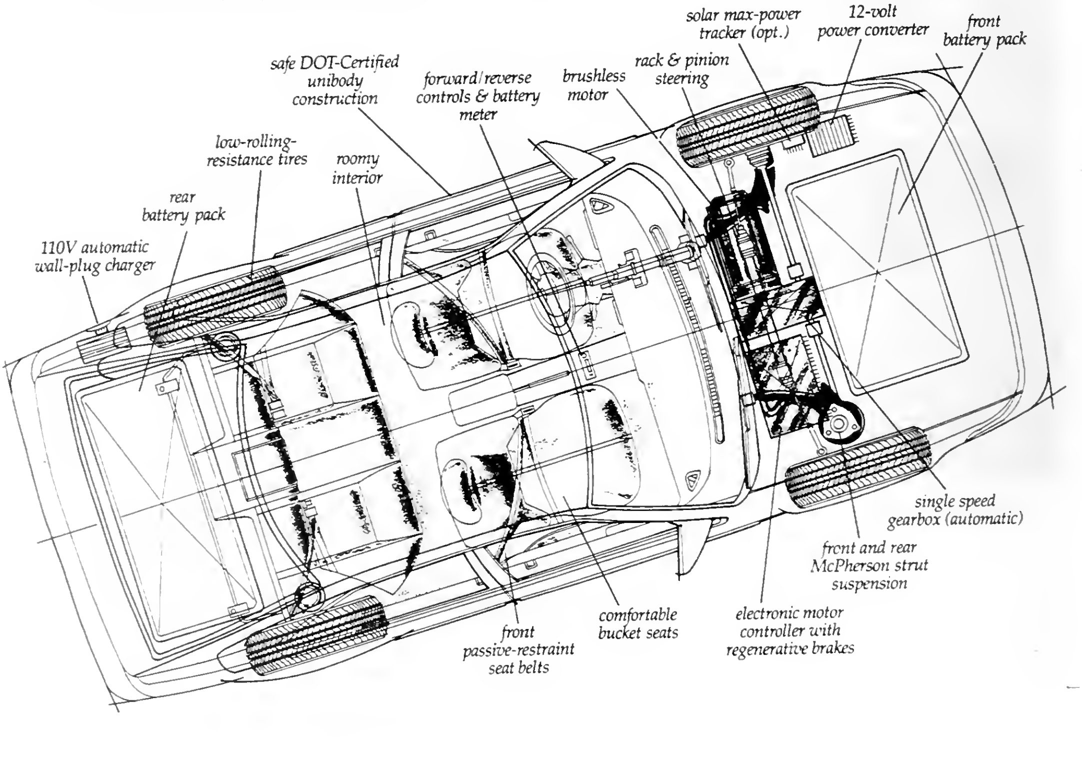
High-Efficiency 42kW AC Induction Drive System with Direct-Drive and Regenerative Braking, Tri-Power Selector, Sealed Maintenance-Free Batteries, Dual Airbags, Power-Assist Brakes, Electric Heater/Defroster, 12V DC-DC Converter, Battery Level Gauge (Digital Amp-Hour Meter), Onboard Battery Charger (1.6kW/110VAC standard for Lead Acid model, 3kW/220VAC standard for NiMH), Reclining Cloth Front Bucket Seats, All-Season Radial Tires, Exterior Color White (unless otherwise noted), Solectria Owner's Manual

OPTIONS

AM/FM Stereo with Cassette
AM/FM Stereo with CD
Air Conditioning with CFC-Free Refrigerant
Analog Ammeter *or* Analog Voltmeter
Rear Window Defogger
Cabin Preheat

ADDITIONAL OPTIONS *(for Lead Acid Battery model only)*

Automatic Battery Thermal Management System – for optimal battery performance and life in cold-climate conditions
Onboard Battery Charger Upgrade to 3kW/220VAC, 3.5-Hour Full Recharge



E-10 Electric Fleet Pickup

SOLECTRIA

THE LEADER IN ELECTRIC VEHICLE TECHNOLOGY

With over one million miles of on-road experience, Solectria presents the E-10 pickup truck...

Offering state-of-the-art electric vehicle technology in a safe and comfortable pickup truck, the Solectria *E-10* met *all* of the grueling requirements established by the nationwide electric utility industry and U.S. Department of Energy coordinated EV America program.

The Solectria *E-10* features smooth, whisper-quiet, shift-free operation, regenerative braking, a standard size hinged bed, and a convenient onboard charger. A Tri-Power Selector facilitates efficient driving and maximizes battery life, while an optional battery thermal management system maintains range in cold weather. Rapid charging is available with the optional Hughes Inductive Charging Port.

Solectria EVs have earned a reputation for low maintenance cost and high reliability in fleet operation. They deliver reliable performance in challenging weather and geographic conditions ranging from Arizona to Vermont.

User-friendly Solectria EVs make a positive environmental statement without sacrificing personal comfort.

Solectria ... *the leader in electric vehicle technology.*

VEHICLE SPECIFICATIONS

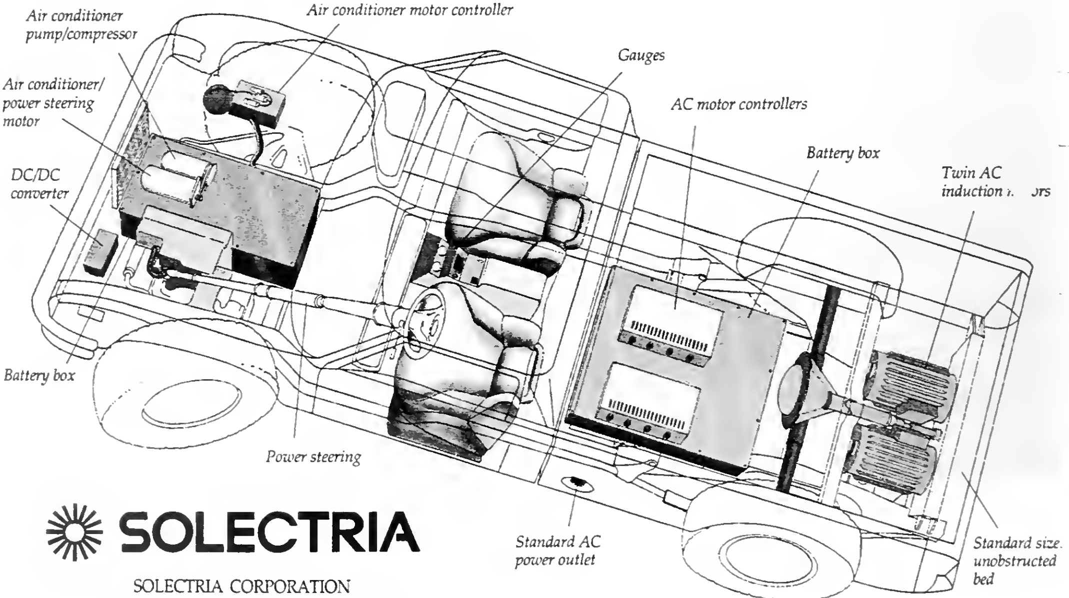
System Power	64 kW
Gradability	28%
Top Speed	70 mph
Efficiency @ 45 mph	230 Whr/mi
Acceleration, 0-30 mph	7 sec
0-50 mph	15 sec.
Curb Weight	4050 lb
Range @ 45 mph	60 mi
Payload	550 lb

Standard Equipment

High-Efficiency AC Induction Drive System with Direct-Drive & Regenerative Braking, Tri-Power Selector, Sealed Maintenance-Free Lead Acid Batteries, Driver's Side Airbag, Power-Assist Brakes, Power Steering, Electric Heater/Defroster, 12V DC-DC Converter, Battery Level Gauge (Digital Amp-Hour Meter), Onboard Battery Charger (3kW/220VAC), Voltmeter, Ammeter, All-Season Radial Tires, Standard Size Bed, Exterior Color White (unless otherwise noted), Solectria Owner's Manual

Options

AM/FM Stereo with Cassette
Air Conditioning with CFC-Free Refrigerant
Automatic Battery Thermal Management System
Hughes Inductive Charging Port



SOLECTRIA

SOLECTRIA CORPORATION
33 Industrial Way · Wilmington, MA 01887 USA
508-658-2231 / Fax 508-658-3224 / www.solectria.com

APPENDIX D Assessment of Different Charging Scenarios

The following analysis assesses the ability of existing transformers and secondary cables to accommodate EVs.

Assumptions:

- 4000 ft^2 homes (80 per cent with A/C, 50 per cent with electrical heating)
- 5 homes per 100 kilovolt-ampere (kVA) transformer (20 kVA per home)
- maximum loading on transformer is 140 per cent (28 kVA per home)
- demographics of such a subdivision would match those of the initial EV market

Season	Base Load (kW)	A/C (kW)	Electric Heat (kW)	Total ** (kW)
Summer	3.5	9.4 * 0.8	0	11.02
Winter	5.2	0	40 * 0.5	25.2
Winter ***	5.2	0	0	5.2

* Based on information provided by Mississauga Hydro.

** Load assumptions based on peak demand period. During the summer months, there is approximately 17 kW of excess capability. During the winter, the excess is reduced to approximately 3 kW.

*** Winter load for non-electrically heated home.

After 9 - 10 pm, the base load demand is reduced. HVAC demand is assumed to remain constant.

Example 1: Charging a 25 kWh battery

15 minutes (quick-charging) requires 100 kW

4 hours (trickle-charging) requires 6.25 kW

8 hours (trickle-charging) requires 3.1 kW

Example 2: Charging a 35 kWh battery

15 minutes (quick-charging) requires 140 kW

4 hours (trickle-charging) requires 8.75 kW

8 hours (trickle-charging) requires 4.38 kW

Maximum loading per transformer is 28 kVA per home. Quick-charging is not viable even if it was the only load on the system.

READER RESPONSE FORM

Electric Vehicles

Technology Development for a Cleaner Environment

1998

We value your comments. By completing this form you will help us increase our understanding of how we can best utilize resources and provide more useful information.

1 Did you find this report of value to your business or operation?

2 What part of the report did you find most useful?

3 Are there technical or economic issues and opportunities not identified in the report? If so please identify.

4 Are there areas in the report we can improve?

5 Any other comments you wish to share?

Respondent's name/organization/address/phone number

Please return a copy of this Reader Response Form by Fax or mail to the following address:

Ontario Ministry of the Environment
Industry Conservation Branch
2 St. Clair Avenue West, 14th Floor
Toronto, Ontario M4V 1L5

Tel: (416) 327-1253
Fax: (416) 327-1261

Attn: Gabriela Teodosiu